RARE/Turbo Spin Echo Imaging with Simultaneous MultiSlice Wave-CAIPI

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Declaration of Financial Interests or Relationships

Speaker Name: Berkin Bilgic

I have no financial interests or relationships to disclose with regard to the subject matter of this presentation.

RARE / TSE Acquisition

- RARE / TSE with ETL~12 is the most commonly used clinical sequence, allowing rapid acquisition by sampling 12 k-space lines per 90° RF and fully refocusing magnetization
- This entails 180° refocusing pulses, making SAR a problem
- Standard 2D TSE (with 3 – 5 mm slices) requires reacquisition if different planes are needed
- In-plane acceleration can improve efficiency, but suffers from intrinsic √R SNR penalty and g-factor noise amplification
- SMS enables acceleration without √R penalty, since number of k-space lines is not reduced
- Wave-CAIPI further improves g-factor

RARE / TSE with SMS

- SMS further aggravates SAR since the power of conventional MultiBand (MB) pulses is proportional to MB factor

- Power Independent of Number of Slices (PINS) pulses [1] have been deployed in SMS-RARE to enable low SAR [2]

- This previous study used blipped-CAIPI for improved parallel imaging [3,4], and allowed MB factor 8 at 2 mm slice thickness

[1] DG Norris et al, MRM'11
[2] DG Norris et al, MRM'14
[3] FA Breuer et al MRM'05
[4] K Setsompop et al MRM'12

RARE / TSE with SMS Wave-CAIPI

- **In this contribution, we push SMS to MB factor 15, thereby enabling whole brain RARE at 1 mm isotropic resolution in 70 sec**

- Two factors that impede attaining such acceleration:
  1. increased SAR of PINS refocusing for 1 mm slices at short pulse duration of 5–6 ms required for efficient RARE
  2. large g-factor penalty incurred by existing parallel imaging methods

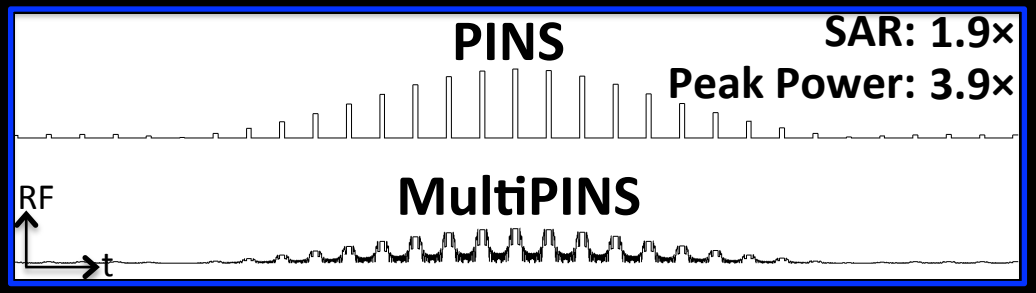
- **We address both issues using:**
  1. **MultiPINS RF pulses [1] that enable low SAR refocusing**
  2. **Wave-CAIPI acquisition [2] that substantially mitigates g-factor**

[1] C Eichner et al, MRM'14
[2] B Bilgic et al, MRM'14

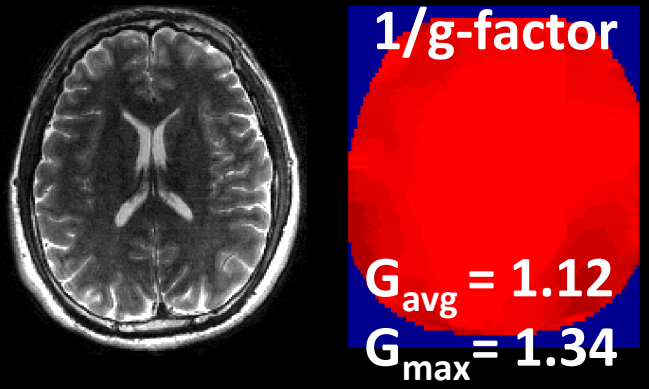
RARE / TSE with SMS Wave-CAIPI

- **In this contribution, we push SMS to MB factor 15, thereby enabling whole brain RARE at 1 mm isotropic resolution in 70 sec**

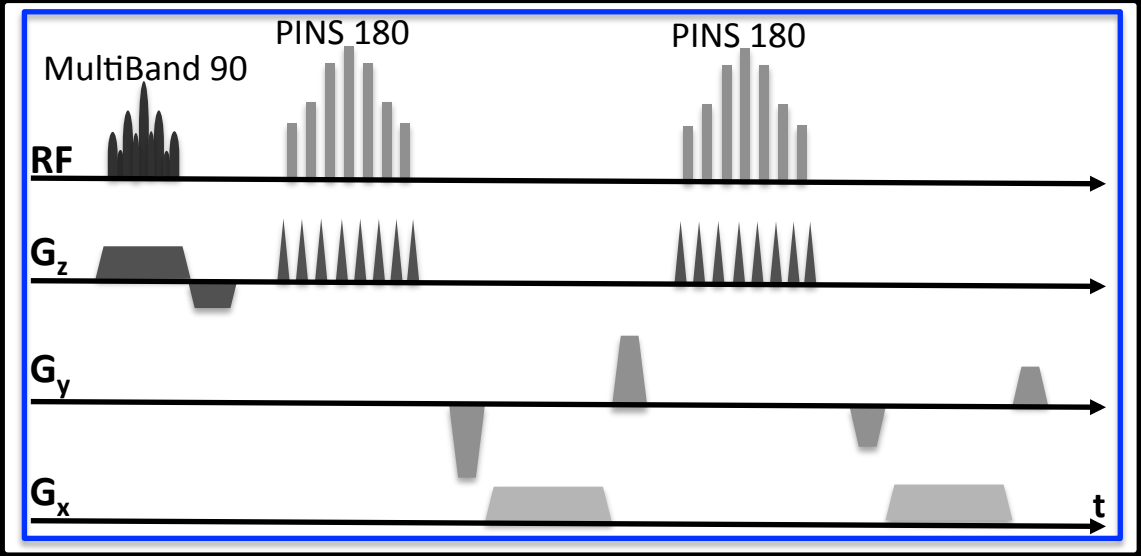
- At MB 15,
  SAR of PINS is **1.9×** of MultiPINS
  Peak power of PINS is **3.9×** of MultiPINS



- Max and average g-factor of Wave-CAIPI are **1.34** and **1.12**



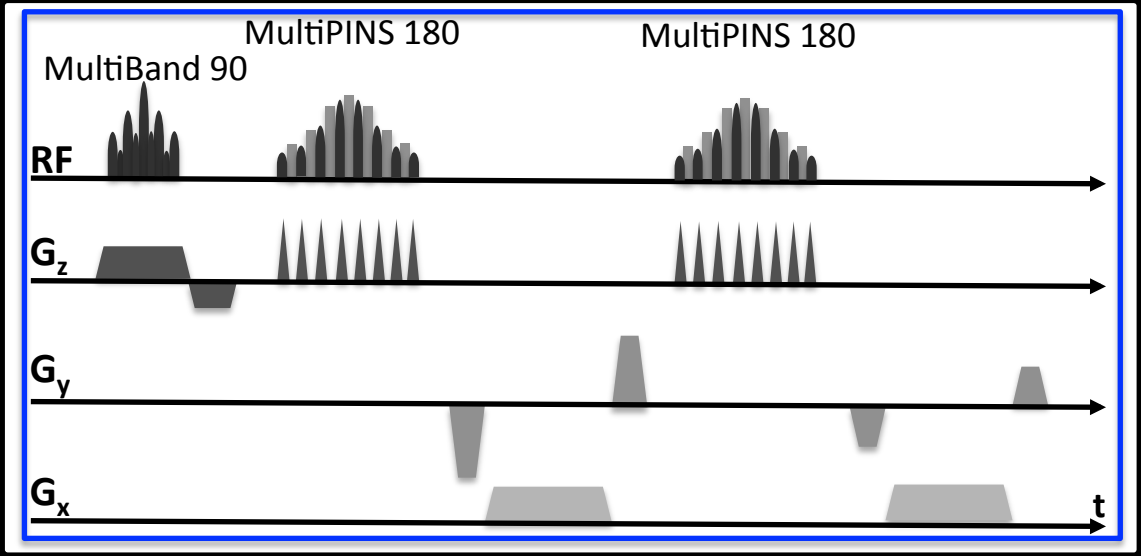
RARE / TSE with MultiPINS refocusing & SMS Wave-CAIPI



Shown for Echo Train Length (ETL) = 2

- PINS pulses are played only *between* the gradient blips

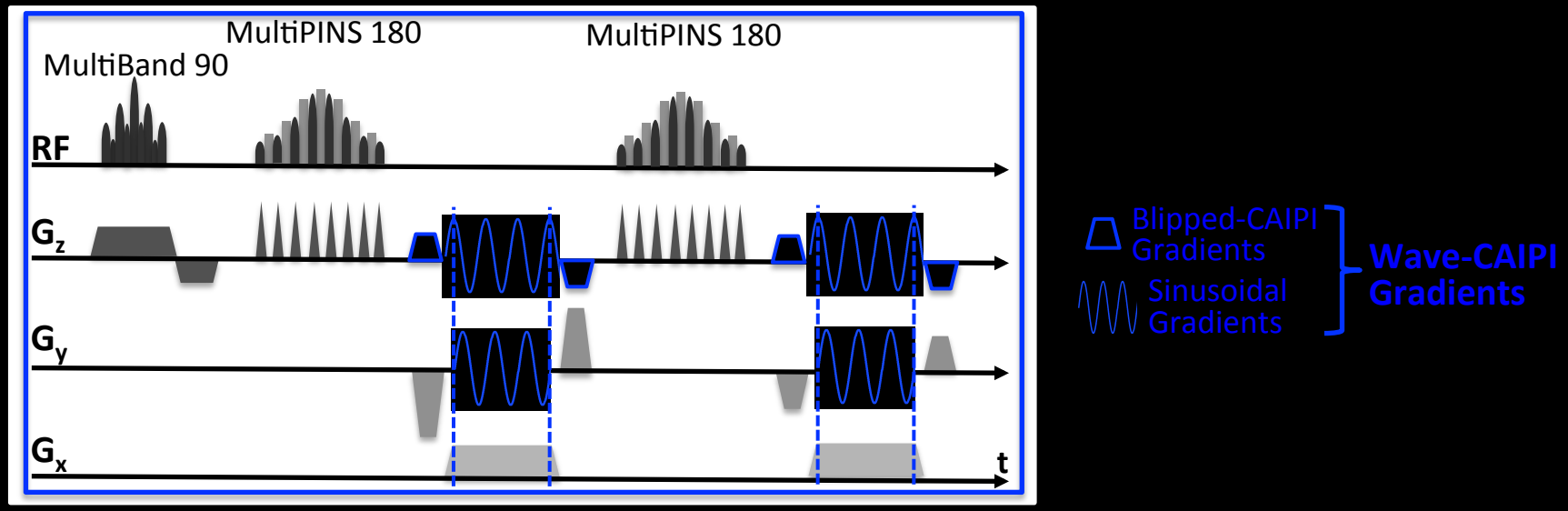
RARE / TSE with MultiPINS refocusing & SMS Wave-CAIPI



Shown for Echo Train Length (ETL) = 2

- PINS pulses are played only *between* the gradient blips
- MultiPINS uses the intervals *during* the blips to play MB pulses
- This leads to reduced peak power and SAR

RARE / TSE with MultiPINS refocusing & SMS Wave-CAIPI



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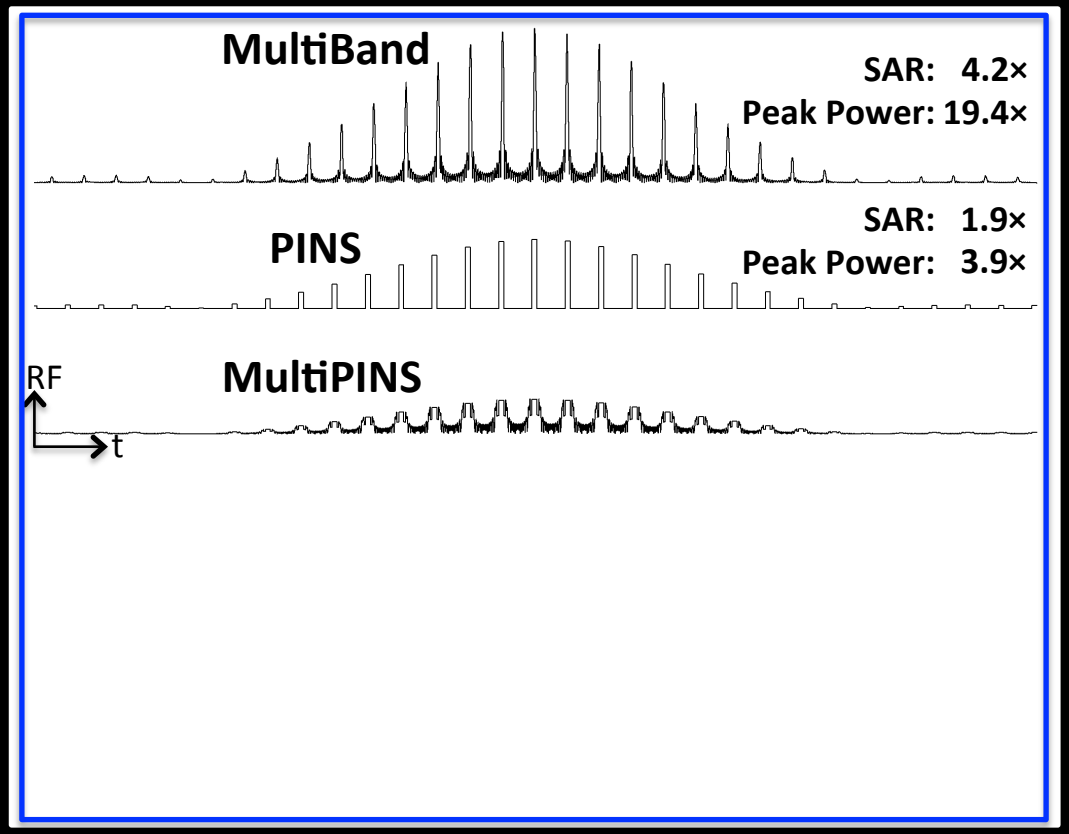
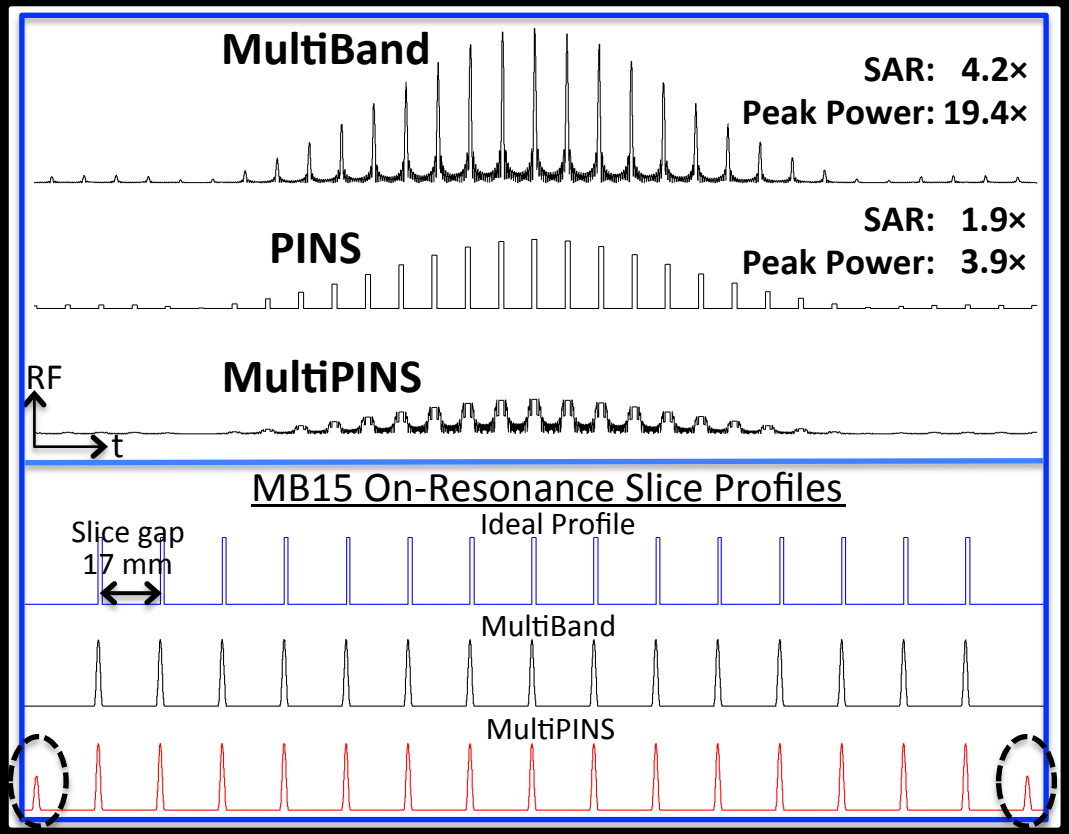
MultiBand, PINS & MultiPINS refocusing for MB15



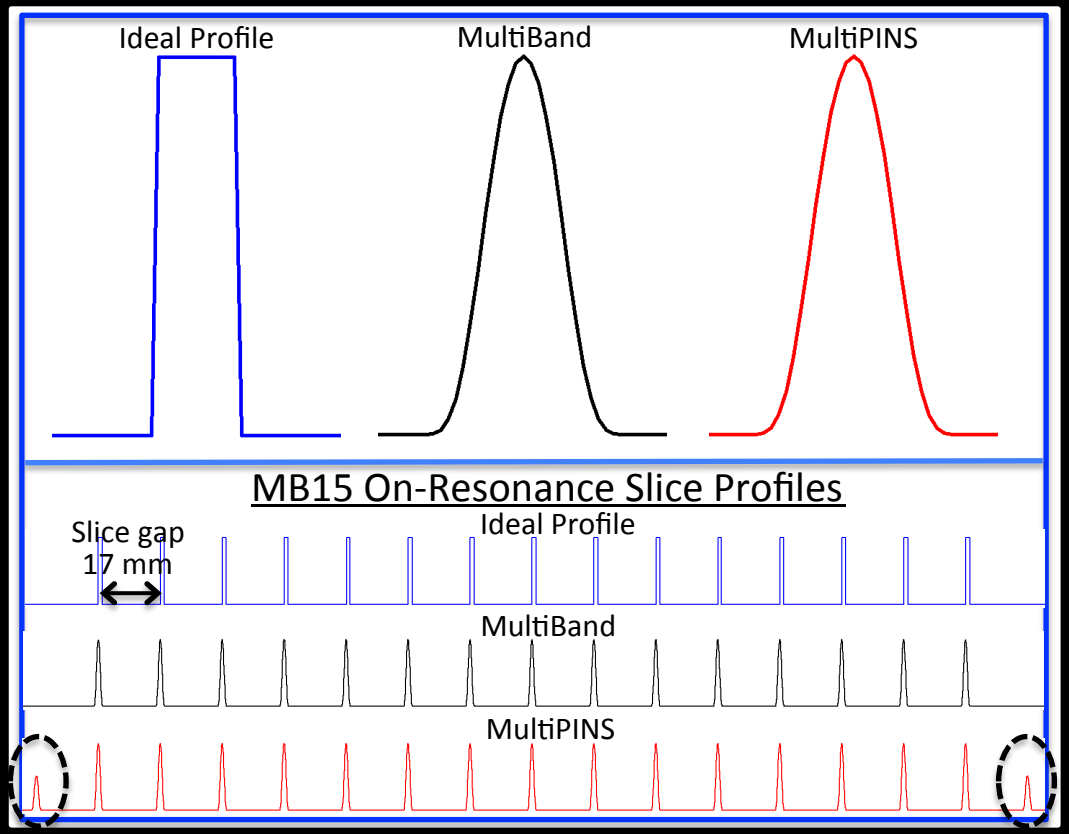
- MultiPINS dramatically reduces peak power & SAR
- MultiBand and PINS exceeded the SAR limit and could not be played
- Time-bandwidth product = 2.4

MultiBand, PINS & MultiPINS refocusing for MB15



- MultiBand & MultiPINS have similar refocusing profiles
- Additional sidelobes are from periodic PINS component

MultiBand, PINS & MultiPINS refocusing for MB15



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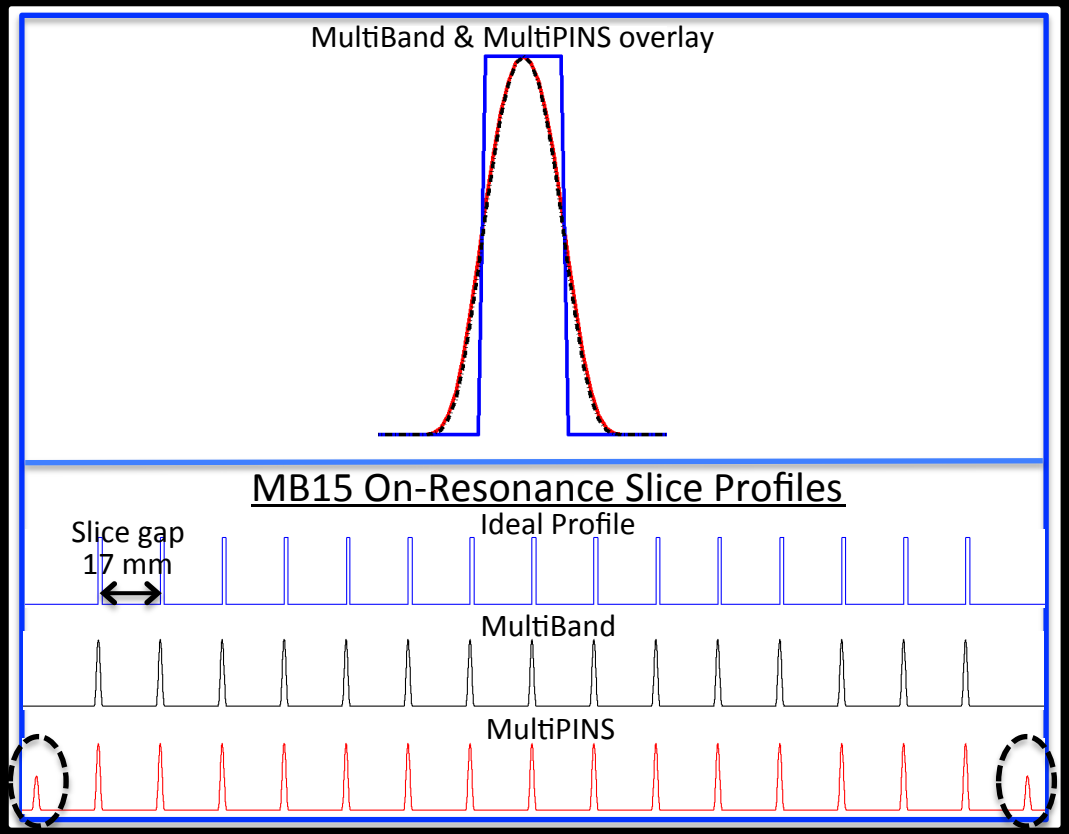
MultiBand, PINS & MultiPINS refocusing for MB15



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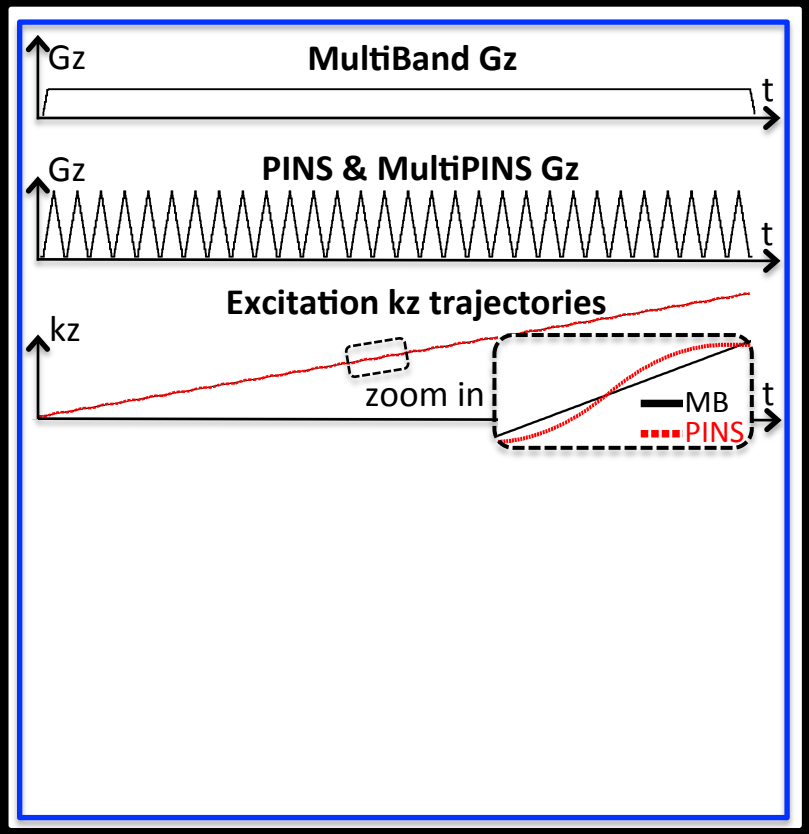
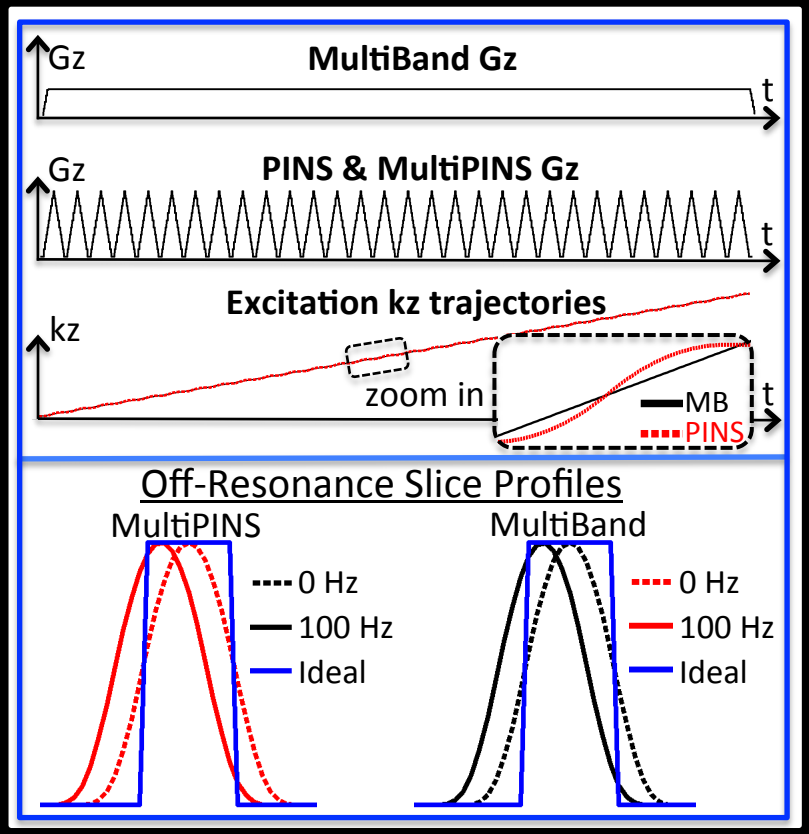
MultiBand, PINS & MultiPINS refocusing for MB15



- Despite differences in gradient waveforms, k-space traversal of all three pulses is very similar
- As such, MultiPINS exhibits good off-resonance performance

MultiBand, PINS & MultiPINS refocusing for MB15

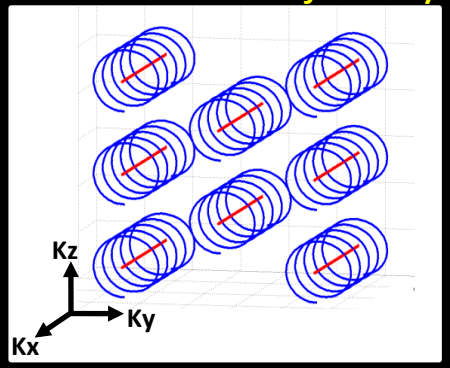


- Slice profile of MultiPINS at 100 Hz off-resonance is shifted identical to MultiBand
- No slice profile distortion can be observed

Wave-CAIPI for 3D-GRE

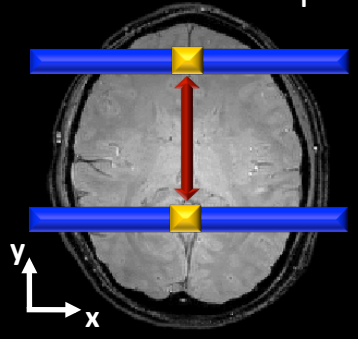
- Wave-CAIPI modifies the 3D GRE trajectory to follow a corkscrew along each readout line [1]
- For accelerated acquisitions, this spreads the aliasing in all 3D dimensions to substantially improve parallel imaging
- Acquisition has the same off-resonance characteristic as Normal GRE (voxel shift in readout), and reconstruction is fully Cartesian

Wave-CAIPI trajectory



Normal GRE

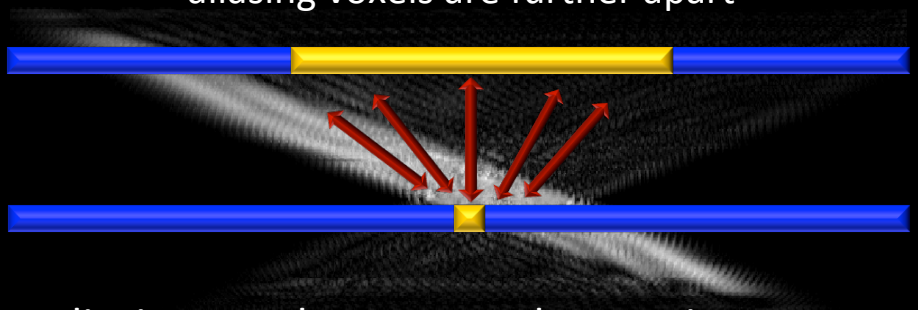
two voxels collapse



R=2 acceleration in Ky

Wave-CAIPI

aliasing voxels are further apart

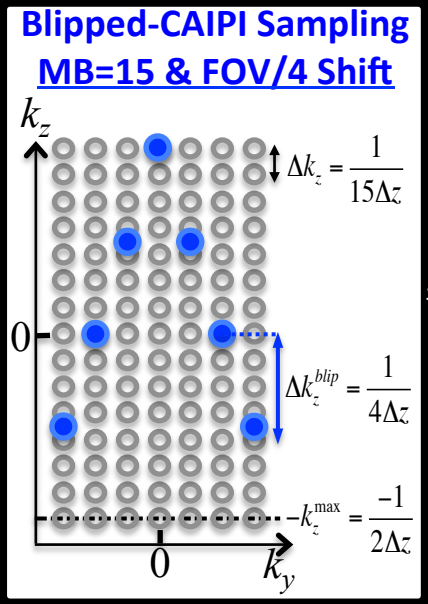


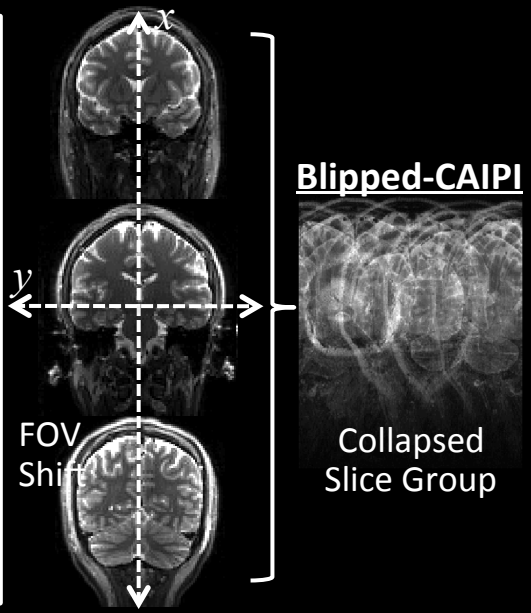
Aliasing voxels are spread out to increase the variation in coil sensitivity profiles:

Improved G-Factor

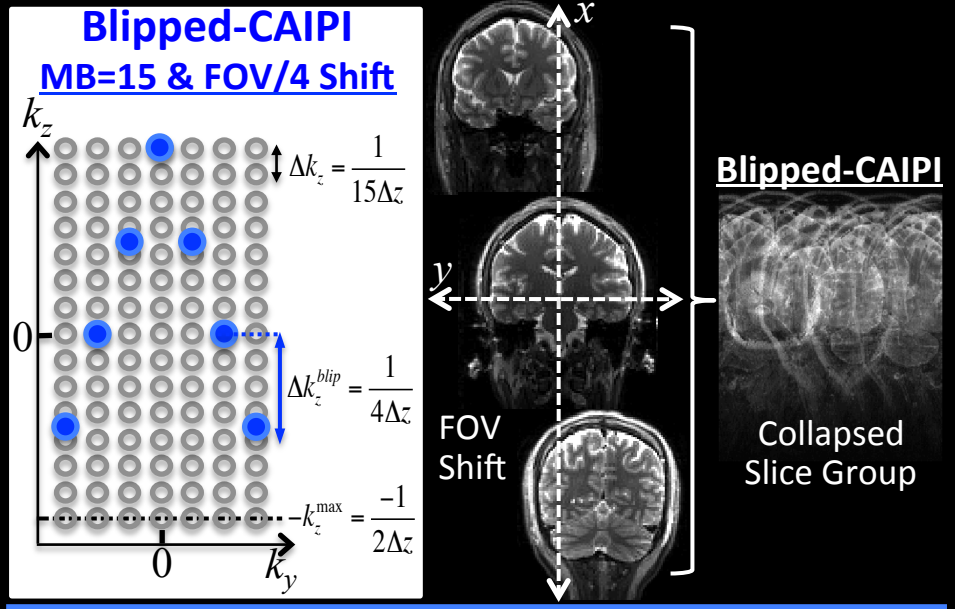
[1] B Bilgic, MRM'14

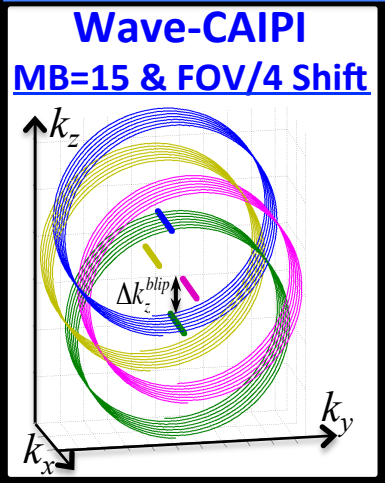
Blipped- and Wave-CAIPI for SMS

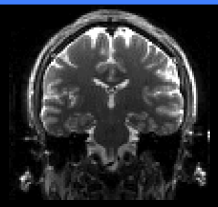




Blipped- and Wave-CAIPI for SMS



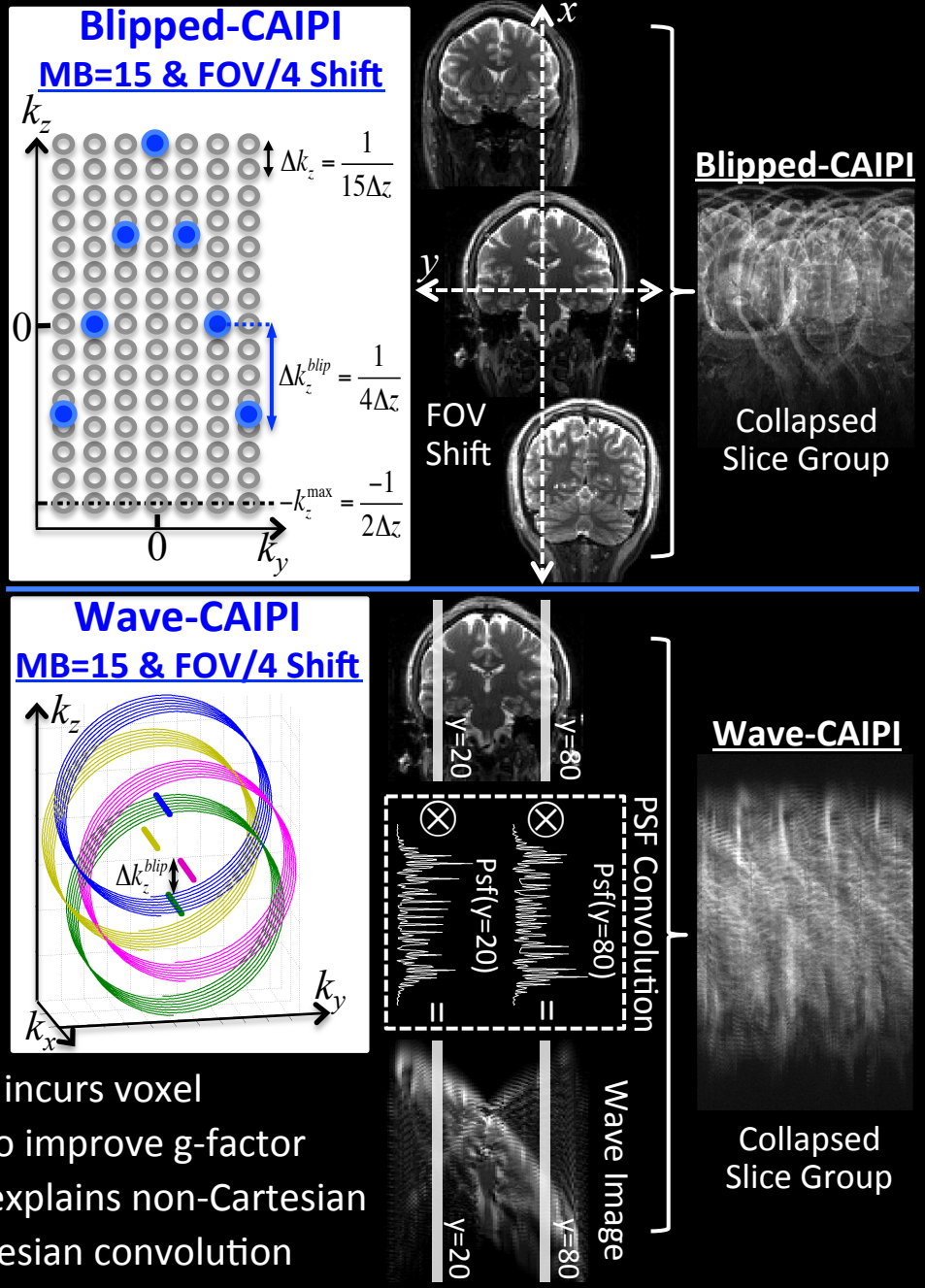




Voxel Spreading

- Helix trajectory incurs voxel spreading in 3D to improve g-factor

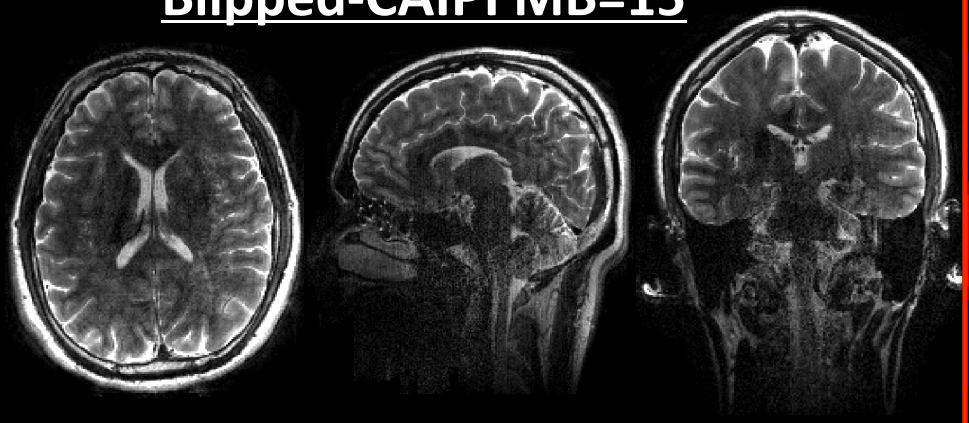
Blipped- and Wave-CAIPI for SMS



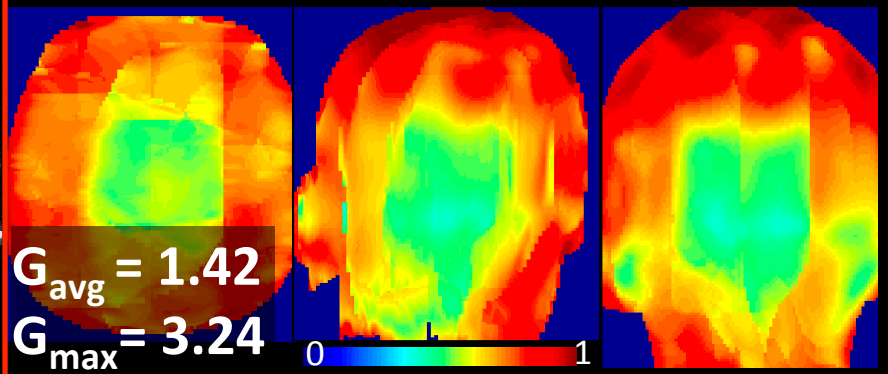
- Helix trajectory incurs voxel spreading in 3D to improve g-factor
- PSF formalism explains non-Cartesian sampling via Cartesian convolution

RARE / TSE @ 3T, 1 mm^3 voxels
ETL=12, T_{acq}=70 sec

Blipped-CAIPI MB=15



1/g-factor: Blipped-CAIPI MB=15



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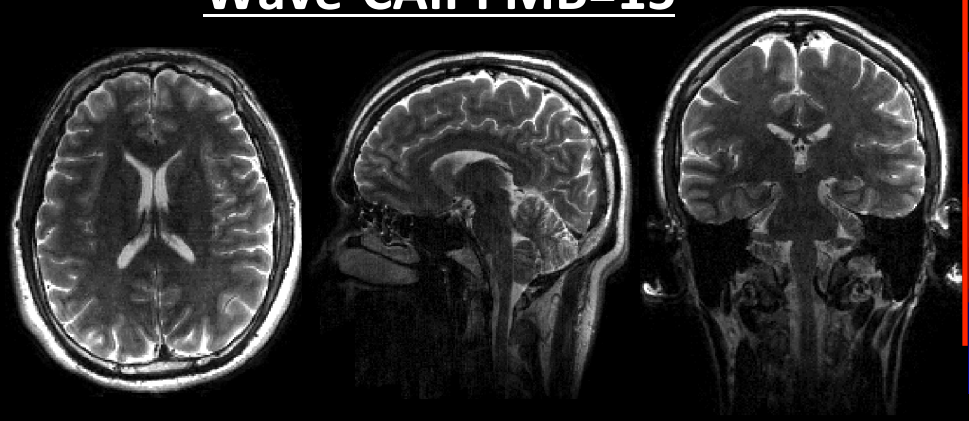
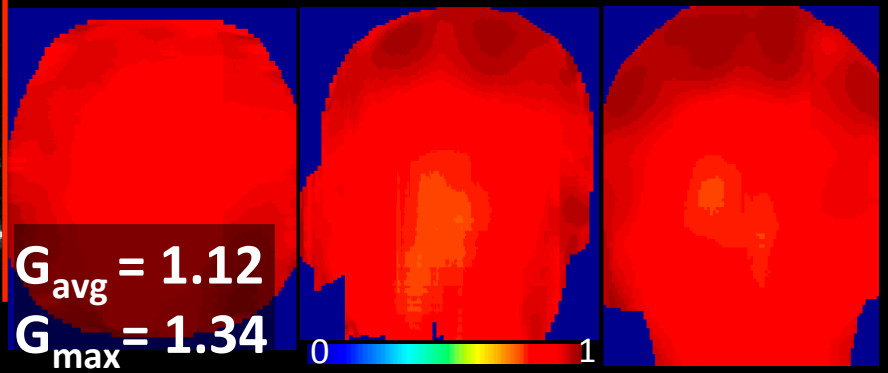
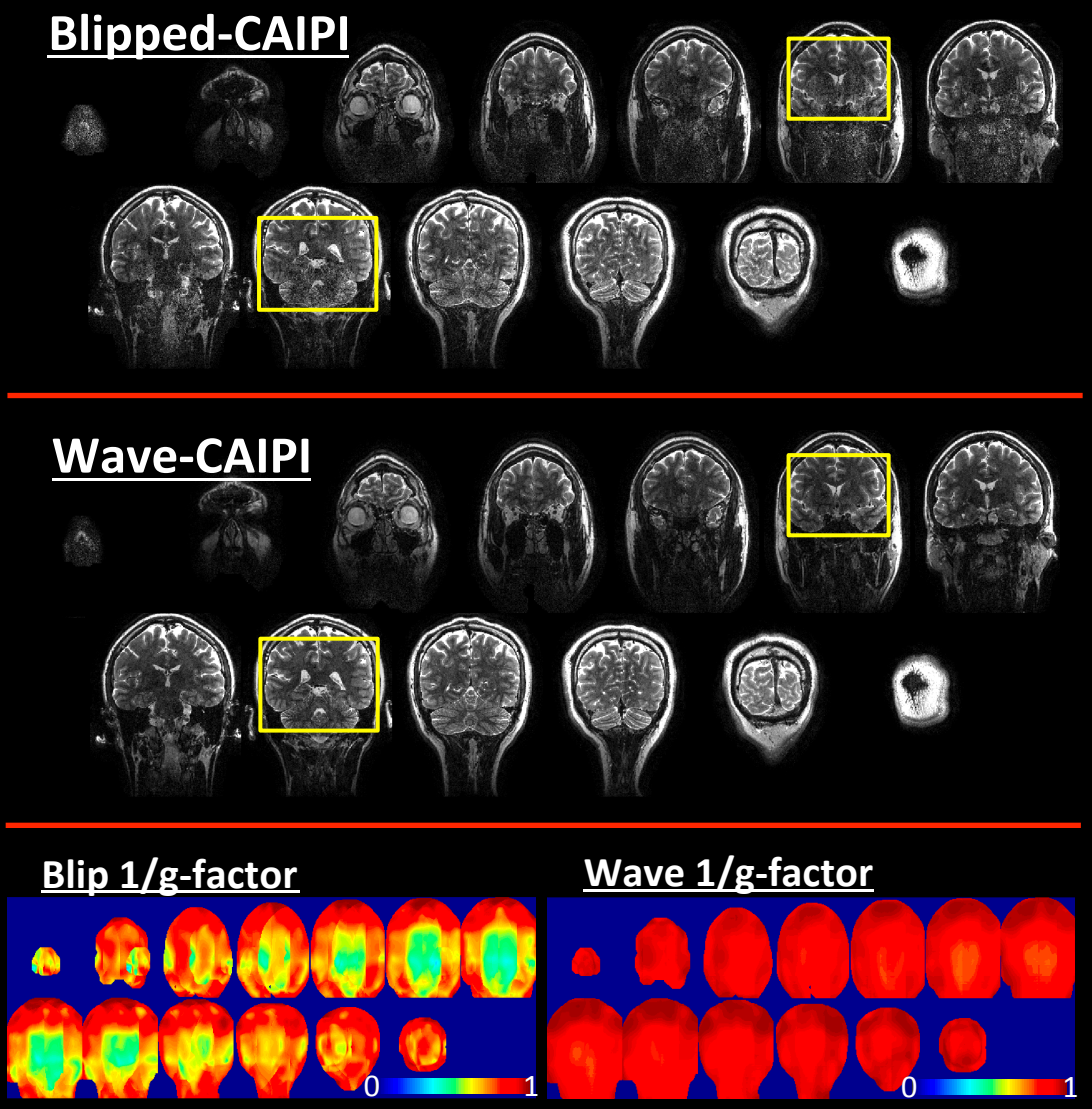


1/g-factor: Wave-CAIPI MB=15



avg over 3mm slabs

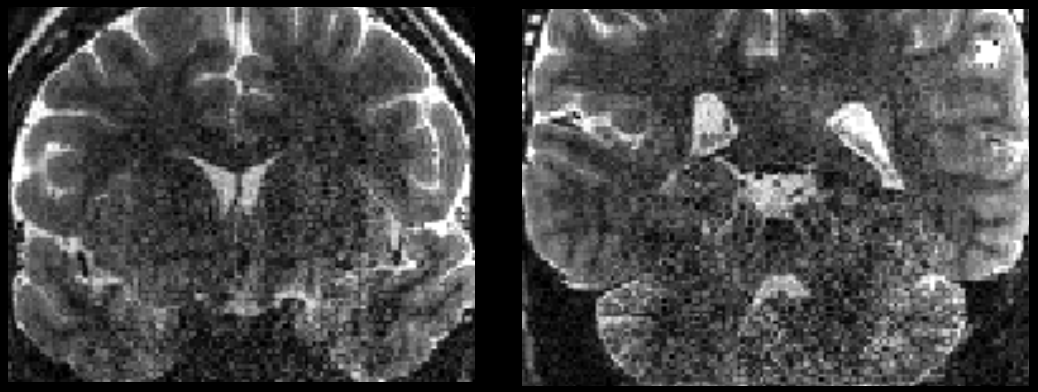
MB=15 Unaliased Slice Groups @ 3T, 1 mm^3 iso



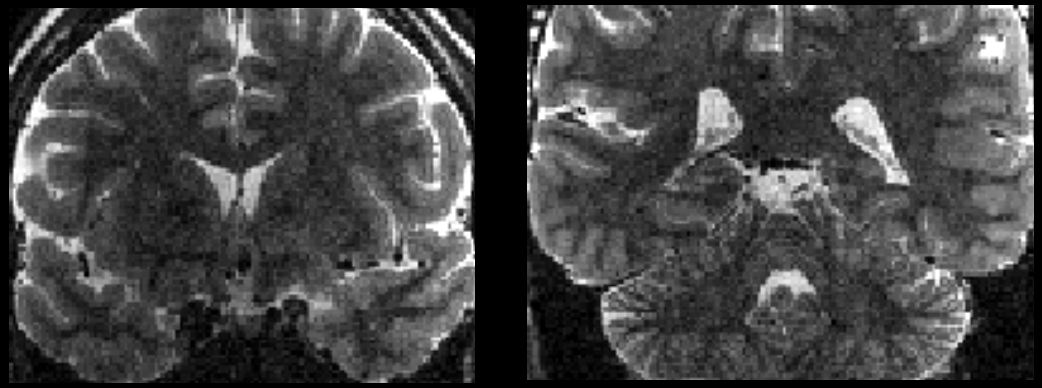
- 255 slices acquired in AP direction to fit all subjects
- For this subject 2 slices without signal => **MB effective=13**

MB=15 Unaliased Slice Groups @ 3T, 1 mm^3 iso, T_{acq} = 70s

Blipped-CAIPI



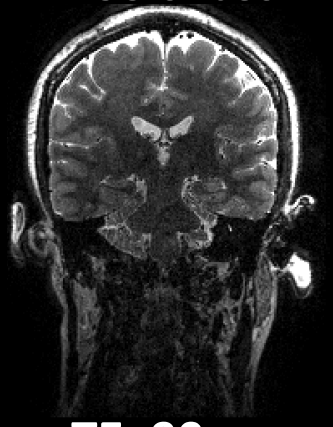
Wave-CAIPI



Magnetization Transfer Contrast: MultiPINS v MultiBand Refocusing

Wave-CAIPI MB_{eff}=13: MultiPINS

255 slices



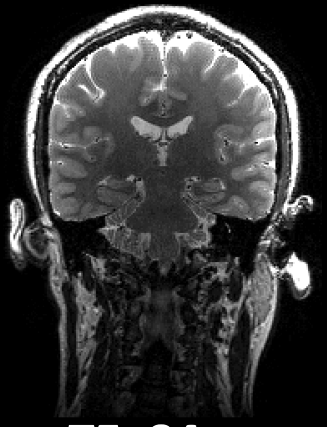
TE=90ms

At similar TE, MTC is amplified:

1. MB part of MultiPINS excites 255 slices => MTC increased
2. PINS part of MultiPINS has large bandwidth => MTC increased

Normal TSE MB1: MultiBand

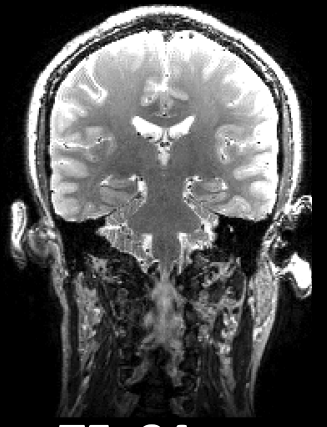
14 slices



TE=84ms

Reduced signal due to MTC

1 slice

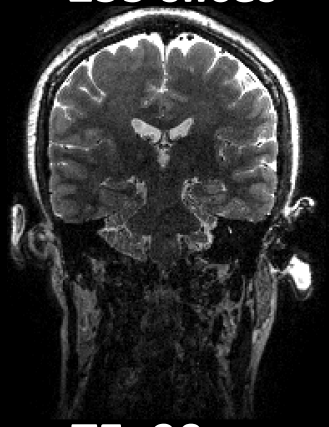


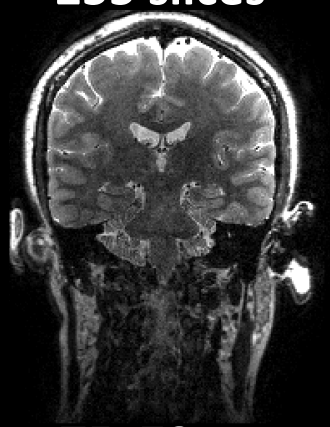
TE=84ms

No MTC

Magnetization Transfer Contrast: MultiPINS v MultiBand Refocusing

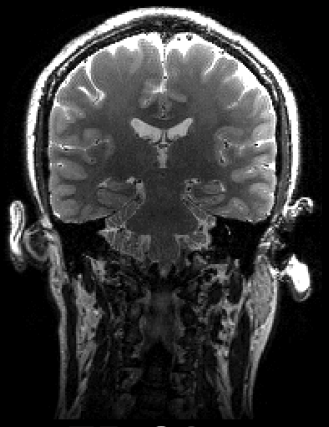
Wave-CAIPI MB_{eff}=13: MultiPINS

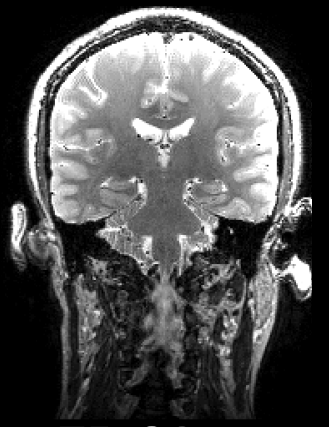




Reducing TE leads to similar MTC as MultiBand MB1

Normal TSE MB1: MultiBand

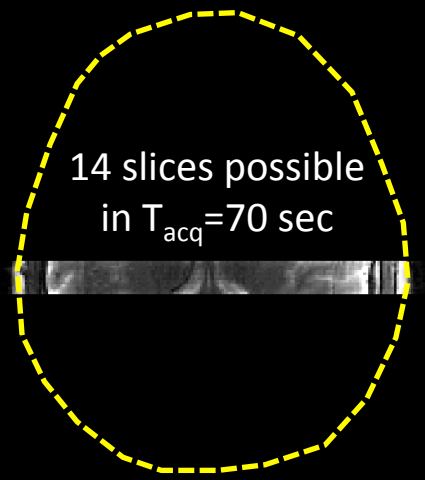




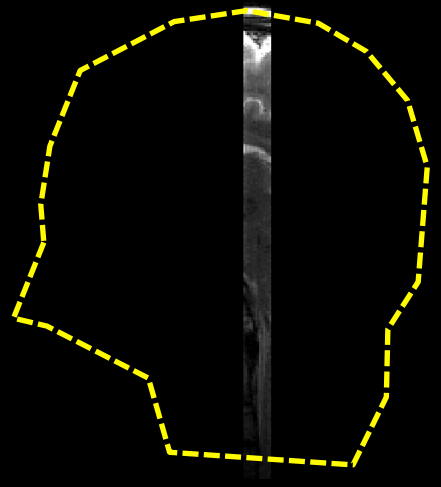
Reduced signal due to MTC

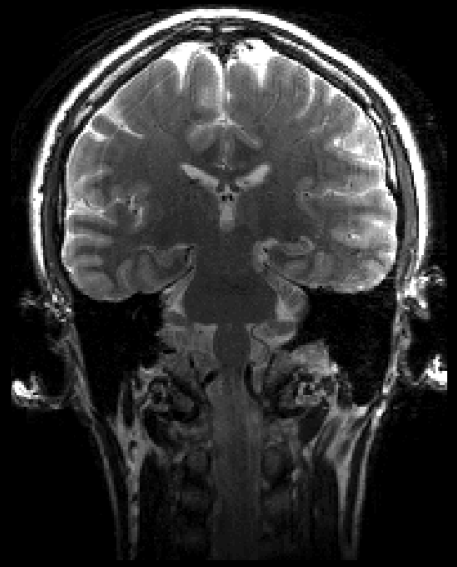
No MTC

SMS Wave-CAIPI at MB 15 allows whole-brain RARE / TSE @ 1 mm^3 iso in 70 sec



Normal TSE MB1





Wave-CAIPI MB=15

SMS Wave-CAIPI at MB 15 allows whole-brain RARE / TSE @ 1 mm^3 iso in 70 sec

- Made possible by
  1. MultiPINS refocusing => 1.9× less SAR than PINS
  2. Wave-CAIPI acquisition => G_{avg} = 1.12 G_{max}= 1.34

- Isotropic voxels permit reformatting in arbitrary plane:
  No need to acquire multiple orientations

- Matlab software and data online for SMS Wave-CAIPI:
  martinos.org/~berkin

- **Acknowledgement**

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Thank you for your attention